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Effect of Flow Rate on Taste Intensity Responses in Humans[1]

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MEISELMAN, H. L., H. E. BOSE AND W. E. NYKVIST. *Effect of flow rate on taste intensity responses in humans.* PHYSIOL. BEHAV. 9 (1) 35–38, 1972.—The effect of flow rate on magnitude estimations of sodium chloride and sucrose was studied, using a specially constructed tongue chamber. Magnitude estimations of taste intensity were obtained for 1.0 M solutions of each compound flowing over the lateral surface of the tongue at rates of 2, 5, and 8 cc/sec. Taste intensity significantly increased as a function of flow rate. Possible mechanisms of this effect were discussed. It was concluded that flow rate is an important variable to control and study in taste research.

Flow rate   Taste intensity

GUSTATORY research has rarely used flow rate of the stimulus as an independent variable. Cohen, Hagiwara and Zotterman [6] reported that the response of single fibers of the cat's chordatympani nerve to water was dependent on the flow rate of the water. Switsky [25] demonstrated that there is a marked reduction of the transient response of the summated chordatympani activity when a stimulus solution is flowed slowly (less than 0.21 cc/sec) over the anterior surface of a rat's tongue. Feallock [10] measured perceived intensity of quinine hydrochloride solutions presented to a small area of the dorsal tongue surface of human observers. He reported that for 0.02 mM and 0.06 mM quinine hydrochloride, perceived magnitude increased with flow rate from 1.7 cc/sec to 4.4 cc/sec and then decreased at 14.6 cc/sec. His presentation of the data assumes a smooth decrease in perceived magnitude beginning at 4.4 cc/sec. At lowest quinine hydrochloride concentration (0.002 mM), he observed a gradual decline in perceived magnitude from 1.7 cc/sec to 14.6 cc/sec.

The degree of flow rate control of gustatory stimuli has varied from experiment to experiment, although there has been a tendency for those doing human psychophysical experiments to exercise more control than those doing electrophysiological experimentation. In research involving electrophysiological recording from one of the nerves innervating taste receptors, some investigators have specified the total volume of solution flowed over the tongue [7, 14, 16, 20]. Others have specified the total time during which the solution was presented but have not specified the solution volume [4, 9].

Halpern and his colleagues [11, 12, 13] and Cohen, Hagiwara and Zotterman [6] have specified both the volume and duration of flow but did not determine if the flow rate was constant.

In contrast to the situation in electrophysiological studies, human psychophysical studies using a flowing stimulus have often controlled flow rate [1, 2, 3, 5, 17, 24]. In these experiments, the flow rate was specified at values between 2.5 and 5.0 cc/sec. As with the electrophysiological experiments, several psychophysical studies have specified only the duration of stimulus flow while others have specified only the volume of flow [18]. Many investigators have given no details of flow volume, duration, or rate.

The present research was undertaken to design an apparatus to control the rate of taste stimulus flow over the tongues of human observers, and to determine whether flow rate exercises a significant effect on taste intensity response of humans.

METHOD

In order to maintain a constant flow rate of test solutions, a tongue chamber was constructed from clear Plexiglas, stainless steel pins, plastic tubing and connectors.

A solution entering the chamber is divided into two equal streams and directed over the lateral surfaces of the tongue before being siphoned away at the rear of the chamber. The subject extends his tongue into the chamber until it is pressed against the stainless steel pins, thus forming two channels with the lateral tongue surface as one wall of each channel. This assures a uniform flow and dispersion of the solution over the lateral surfaces of the tongue which are not in contact with the steel pins. In this way over 90% of the lateral surface of the tongue can be stimulated. Plastic tubing connects the front of the tongue chamber with a two-way stopcock. Either distilled water or the taste solution can be directed into the tongue chamber by turning the stopcock in the appropriate direction.

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[1]This paper reports research undertaken at U.S. Army Natick (Mass.) Laboratories. The findings in this report are not to be construed as an official Department of the Army position.

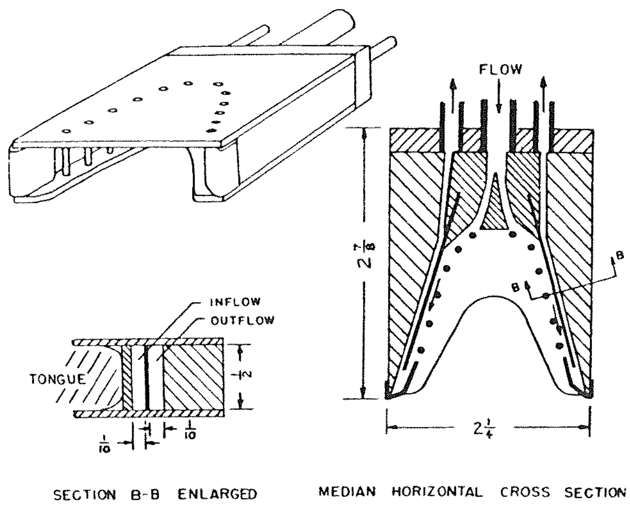

FIG. 1. Three views of tongue chamber: (1) Three dimensional overall views in upper left. (2) Median horizontal cross section in two dimensions. (3) Detailed cross section in two dimensions.

The valve controlling the flow of distilled water was calibrated to deliver 5 cc/sec. The flow rate of the taste solution was controlled by adjusting a flow meter regulator (Fischer and Porter model 53 RT2110 . . . series A2) calibrated in cc/sec. The flow rate was adjustable from 0–10 cc/sec with liquids of specific gravity 1.0 and viscosity 1.0 cps. Each of the valves was mounted on the side of a water bath and connected by plastic tubing to one of two 1-gal polyethylene bottles holding either the distilled water or the taste solution. The bottles sat in a water bath at 34 ± 1°C and were pressurized with nitrogen gas to 2 psi.

Subjects were 25 male volunteers, ages 25–30, chosen from laboratory personnel at the U.S. Army Natick Laboratories. No criteria for subject selection were established. Two groups of ten subjects each were used to determine the effects of three flow rates on the perceived intensity of either 1.0 M sodium chloride or 1.0 M sucrose solutions. Smith [22] demonstrated the effectiveness of using progressively higher concentrations with smaller stimulating areas. The remaining five subjects were used to determine if changes in the concentration of test solutions in the tongue chamber were discernible cues. Solutions of 1.0 M reagent grade sodium chloride or sucrose were prepared with distilled water (refractive index = 1.3330), and placed in the 1-gal polyethylene bottles. They were presented to subjects at flow rates of 2, 5, and 8 cc/sec in the tongue chamber. In order to insure that the tongue chamber remained filled with stimulus, a flow rate of at least 2 cc/sec was required.

Before each testing session subjects were seated before the apparatus and were blindfolded. The subject was then presented with the standard, which consisted of a 5 cc/sec presentation for 5 sec of the taste solution. The standard was assigned a value of ten. Subjects were asked to estimate the magnitude of all later solutions using numbers in proportion to the strength of the standard according to the procedure of magnitude estimation [24]. For example, if the perceived intensity of a sample was twice that of the standard, it was assigned a value of twenty. Five 5-sec presentations of the test solutions at each of the three flow rates were evaluated by each subject. The standard and each test solution were preceded by at least a 15 sec intertrial interval. During this interval, subjects reported magnitude estimations, and the tongue chamber was rinsed with distilled water.

In order to check the maintenance of stimulus strength in the tongue chamber, samples of both taste solutions were obtained from the tongue chamber immediately after a 5 sec flow at each of the three flow rates. A pipet was placed at the extreme front of the tongue chamber, and a small aliquot of the solution was removed. During testing, the tight fit of the tongue chamber precluded dilution from saliva entering the chamber, thus insuring stimulus concentration stability throughout the chamber. The refractive index of each sample was obtained for the sodium chloride samples using a hand refractometer (American Optics, Model 10402), and for the sucrose samples using a precision refractometer (Bausch and Lomb, Model 33-45-58). The concentration of each of the samples was then determined by comparison of their refractive indices with the refractive indices of standard solutions prepared at this laboratory. The sucrose refractive indices all corresponded to a molarity of 1.00. For sodium chloride at 2 cc/sec the refractive index corresponded to 0.93 M, and at 5 and 8 cc/sec, the indices corresponded to 0.98 M and 0.99 M respectively. Five subjects were used to determine if these sodium chloride molarities could be discriminated on the basis of concentration alone. Using a dorsal tongue flow method described by Meiselman [17], the subjects were asked to rate the taste intensity of the two solutions when presented in a random sequence. There was no significant difference (dependent t, $p > 0.05$) between magnitude estimations of 0.93 M and 0.99 M sodium chloride.

In order to determine whether changes in flow rate produced concomitant changes in pressure within the chamber, pressure measurements were made. Using fine stainless steel tubing, pressure taps were constructed to measure the stagnation pressure and the undisturbed pressure at the three test flow rates. Stagnation pressure at a flow rate of 8 cc/sec was found to be 0.3 mm Hg more than that at 2 cc/sec, while the undisturbed pressure showed no discernible change between 2 and 8 cc/sec. Since the tongue experiences a pressure somewhere between the undisturbed and stagnation values, and the maximum stagnation pressure change of 0.3 mm Hg corresponds to only 0.058 psi of water, it is doubtful that pressure effects produced discernible cues.

Another potentially confounding factor is turbulence of the stimulus within the tongue chamber. Shames [21] reports critical values for turbulence based on calculation of the Reynolds number. Since the stimulation area was 0.05 in.^{2}, the highest flow velocity 0.405 ft/sec, the kinematic viscosity 7.5×10^{-6} ft^2/sec, and the equivalent of diameter 0.0139 ft, then the Reynolds number at the highest flow rate is 750.0. According to Shames [21] a Reynolds number of 2300 is the lower critical value of turbulence. Therefore, only laminar flow was present under the experimental conditions. There is no turbulence.

RESULTS AND DISCUSSION

Figure 2 presents the geometric mean magnitude estimations as a function of flow rate. The geometric mean is the appropriate measure of central tendency for magnitude estimation data [23]. For both sodium chloride and sucrose, perceived intensity increases monotonically with flow rate. An analysis of variance of the mean magnitude estimations, at each flow rate, demonstrated a significant difference between flow rates

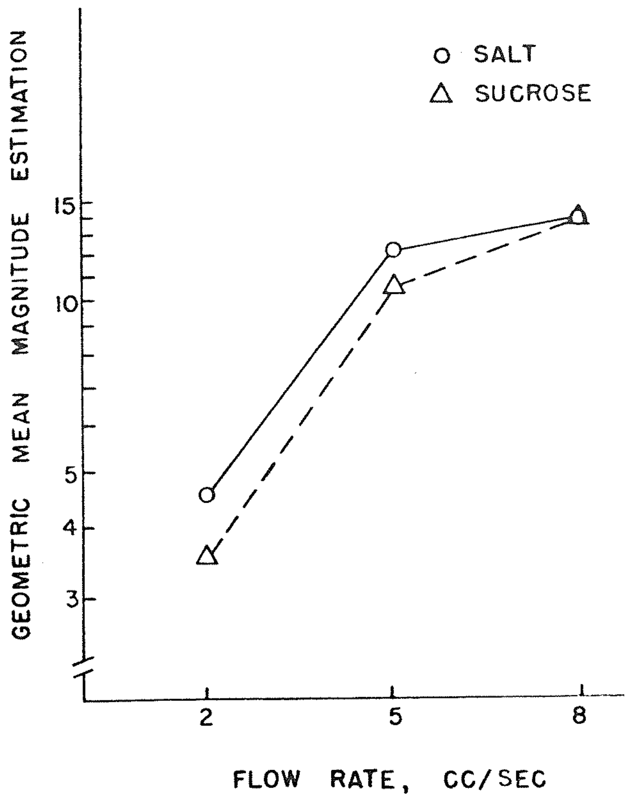

FIG. 2. Geometric mean magnitude estimation as a function of flow rate. Each point represents an average of fifty responses to either 1.0 M sodium chloride or 1.0 M sucrose.

for 1.0 M sodium chloride ($F = 33.65$, $p < 0.001$), and also for 1.0 M sucrose ($F = 20.81$, $p < 0.001$). More specific Least Significant Difference tests (Li, 1964) showed the geometric means of sodium chloride at 2 cc/sec and 5 cc/sec and those at 5 cc/sec and 8 cc/sec to be significantly different (LSD test, $p < 0.05$). A similar test of significance demonstrated that the geometric mean magnitude estimations of sucrose at 2 cc/sec and 5 cc/sec and the 2 cc/sec and 8 cc/sec were significantly different (LSD test, $p < 0.01$), and those at 5 cc/sec and 8 cc/sec (LSD test, $p < 0.05$). Thus, for each stimulus every flow rate was significantly different from every other flow rate.

Thus, within the conditions of this experiment, and within the range of flow rates tested, the perceived intensity of the solutions increased with increasing flow rate. This is consistent with the electrophysiological findings of a reduced transient in summated chordatympani activity in rat when a stimulus is presented at low flow rates [25]. Since the upper end of the function relating perceived intensity to flow rate might be approaching asymptote, it is possible that there is an upper limit to the enhancement of intensity by flow rate. At some relatively high flow rates, the stimulus may move over the tongue surface at a rate sufficiently high to interfere with the receptor process. This would result in a response decrement. Thus, the function relating perceived intensity to flow rate is possibly an inverted "v" shape. Further experimentation will examine the form of this function. If this relationship changes with changes in concentration of the stimulus solution, then a family of psychophysical curves would be needed to show these complex relations.

Indeed, Feallock [10] reported that at low quinine hydrochloride concentrations (0.002 mM), increased flow rate always produced lower intensity ratings. At medium and high concentrations (0.06 and 0.02 mM respectively) perceived intensity increased with flow rates up to 4.4 cc/sec and decreased at 14.6 cc/sec. Unfortunately, the lack of data relating perceived intensity to flow rates between 4.4 and 14.6 cc/sec, make a direct confirmation of the present findings impossible. An increase in perceived intensity with flow rates of at least 8 cc/sec is still consistent with Feallock's results which in addition suggest that this phenomenon can be extended to other lower concentrations. Dzendolet [8] has demonstrated a positive relationship between the rate at which electrically produced ions are presented to single taste papillae and the gustatory threshold for such stimulation. He concluded that the sodium chloride threshold was a function of the rate at which ions are presented to the receptors. If the rate of presentation of electrically produced ions is comparable to flow rate, then Dzendolet [8] is in agreement with Feallock [10] supporting the flow rate dependence for both sodium chloride and quinine hydrochloride at concentrations below the one used in the present study.

While it is premature to suggest a mechanism of this flow effect before the complete relationships among flow rate, stimulus concentration, and perceived intensity have been worked out, the following three hypotheses deserve consideration. (1) Increased flow rate might mimic increased physical concentration. That is, flow rate might achieve its effect by affecting the probability with which a stimulus element is available to a receptor site. At higher physical concentrations there are more available stimulus elements, thus increasing the probability that most or all receptor sites will be filled at a given time. Similarly, at higher flow rates, there are more available stimulus elements per unit time insuring filling of receptor sites. (2) Flow rate might exert its affect through a mechanism such as diffusion. If diffusion is a factor in the taste receptor process, then flow rate would affect it by changing the effective concentration of the stimulus, thus affecting the perceived intensity of taste stimuli. (3) Lastly, flow rate might act mechanically on the taste receptor. Perhaps the flow rate effect results from mechanical forcing of the stimulus into the taste pore and onto the taste receptor sites. This mechanism would predict that a weak concentration at a higher flow rate would appear as intense as a higher physical concentration at a lower flow rate.

For the time being, it is important that attention be focused on flow rate as a variable in gustatory research. The results of the present study suggest strongly that control of flow rate is necessary for those conducting taste research.

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